

ENERGY DISTRIBUTION OF NEUTRONS FROM RA-D-BE SOURCE

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ABSTRACT. The energy distribution of neutrons from RaD-Be source has been studied with photographic plates. The effect of scattering of these neutrons in lead was investigated also. The neutron peaks in the energy distribution curve correspond to different levels of C^{12} . The discrepancies are discussed.

INTRODUCTION

The neutron energy spectra from Po-Be source has been investigated by various methods (Richards and Demers, year; Whitmore and Baker, 1950; Gursky *et al*, 1953, Elliot *et al*, 1954, Breen *et al*, 1945). Almost in each case the spectra obtained show two general characteristics.

(i) The presence of three peaks of neutrons near 3 Mev, 5 Mev and 7 Mev energies corresponding to the levels of residual nucleus C^{12} at 4.43, 2.5 Mev. and the ground state (Hornyak and Lauritsen, 1948) respectively and

(ii) an average energy of neutrons of about 4.6 Mev. The peak near 5 Mev. has been explained by Whitmore and Baker (1950) due to the presence of a level of C^{12} at 2.5 Mev; however the data from other experimental results show the level structure of C^{12} (Ajzenberg and Lauritsen, 1955) with the first excited level at 4.43 Mev. In view of these conflicting reports an attempt was made to check the energy spectra of the neutrons from Po-Be source. Instead of Po-Be source a RaD-Be neutron source was however used. It is well known from the decay scheme that there is no α emitting nuclide between RaD and Po and as such the α -particles taking part in the reaction producing neutrons from a (RaD+Be) source are those from the decay of Po^{214} . Hence the neutron energy distribution from a RaD-Be source should be identical with that from a Po-Be source. There are however a few low energy γ -rays in the decay of RaD and RaE. Lead absorber was used to cut off these γ 's which fogged the plate slightly which was exposed to this source directly. The spectra obtained in this experiment also show a prominent peak near 5 Mev. Possible reasons for the presence of this peak are discussed.

EXPERIMENTAL PROCEDURES

The RaD-Be source of 20 millicurie strength was used as the source of neutrons and photographic plates were used as detectors. Ilford C-2 plates of

100 microns thickness were mounted radially about the source with the plane of the emulsion horizontal, the distance of the centre of the plate being 10 centimeters from the source. Exposures were given once with the source only and once with lead of thickness nearly one inch surrounding the source. The plates were processed by the usual method of processing thin plates using Ilford ID-19 developing solution.

METHOD OF MEASUREMENT

The proton recoil method has been followed in the experiment described and since it is most extensively used in neutron energy measurements, no detailed descriptions are necessary here. All measurements were done according to the method given by Rosen (1953). The projected length to the emulsion surface of the available tracks were measured. The selection criteria were that only those recoil proton tracks were recorded which had horizontal angles of less than or equal to 15° with the central line and dip angles of less than or equal to 15° in the unprocessed emulsion, further only those tracks were accepted which started and ended within the emulsion.

With these criteria, the corresponding energy of the neutron was obtained using the following procedure. The projected length R_p of a recoil track is related to the absolute range L_p of the proton track in the unprocessed emulsion by the relation $L_p = R_p / \cos \bar{\psi}$ where $\cos \bar{\psi}$ is the average value of the cosine of the angle ψ between R_p and L_p and is a function of the angles θ_{max} and ϕ_{max} which are the maximum values of the half angles θ and ϕ respectively (each equal to 15° in the present case) of the rectangular pyramid formed by the recoil proton track.

The energy of the recoil protons is directly obtained from the range energy curve of Lattes *et al.* The neutron energy E_n corresponding to the recoil proton energy E_p is given by the relation $E_n = E_p / \cos^2 \rho$ where $\cos^2 \rho$ is the average value of the cosine squared of the angle ρ between the incident neutron and the recoil proton directions and is again given as the function of θ_{max} , γ_{max} and ϕ_{max} where γ_{max} is the maximum value of the angle γ that the incident neutron makes with the axis along which the projected lengths of the tracks are measured. This method leads to an error of less than one per cent in the neutron energy E_n for θ_{max} , ϕ_{max} and γ_{max} less than 15° . Finally in order to transform the measured proton energy distributions into the neutron energy distributions the variation of the n - p scattering cross section with neutron energy and the escape probability of the recoil protons from the emulsion surface ((Rosen, 1953) should be taken into account

About 1100 tracks were scanned in the case in which lead absorber was used and 750 tracks were observed for the case in which no absorber was used. A Leitz microscope with 8×100 magnification was used for the measurements,

No corrections were made for straggling effects. The shrinkage factor was taken to be 2.5.

RESULTS AND DISCUSSIONS

The energy distribution curves for both the cases were plotted at the energy interval of 0.5 Mev as shown in the figure 1. There is good agreement of our curves with that obtained by Whitmore and Baker (1950), Elliot *et al.* (1954) and others. The common features are the followings:

- (i) The spectra extend upto the maximum neutron energy of nearly 11 Mev.
- (ii) Neutron peaks are obtained near 3 Mev, 5 Mev, and 7 Mev.

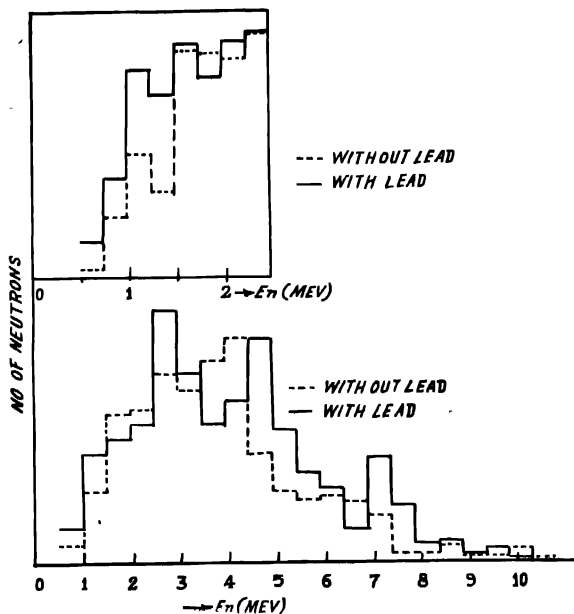


Fig. 1 (bellow) & Fig. 2 (above).

No peak was present near 1 Mev when the plot was at 0.5 Mev energy interval. When the histogram is drawn at an energy interval of 0.25 Mev a small peak is obtained near 1.5 Mev.

The low energy sides of both the spectra were plotted (figure 2) at an interval of 0.25 Mev neutron energy to study the effect of inelastic scattering of neutrons in lead. No sharp difference is observed between the two curves.

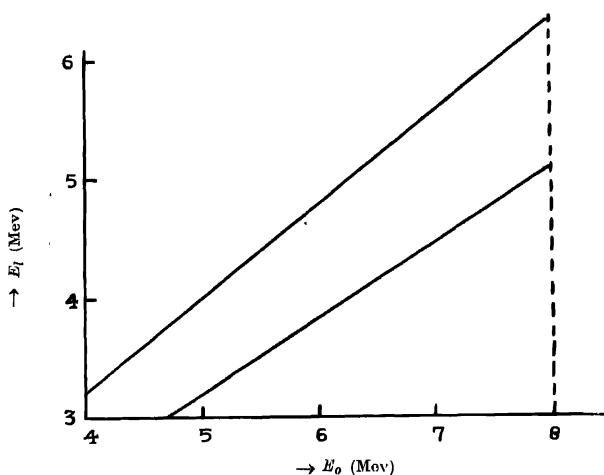


FIG. 3

A thorough discussion has been made by Whitmore and Baker (1950) to give proper explanation of the energy spectra of neutrons obtained from Po-Be source, examining all the possible discrepancies. In the curve obtained in this experiment almost all the characteristics noted by Whitmore are present. The peak near 5 Mev or the 2.5 Mev level of C^{12} is absent in many other experiments (Powell, 1943; Champion and Powell, 1944, Bradford and Bennett, 1950). Experiments detecting γ 's and γ - γ coincidences (Ajzenberg and Lauritsen, 1955) show the presence of 4.43 Mev level as the 1st excited state of C^{12} . These evidences indicate that the peak near 5 Mev is not due to excitation of any level of C^{12} . The comparison of the theoretical neutron spectra (Whitmore and Baker, 1950) considering only the ground state and first excited state with that of the experimentally obtained shows that the intensity of the higher energy sides i.e. from 6 Mev to 11 Mev is much reduced in the experimental curve. All these discrepancies may be due to the elastic scattering of the neutrons. The neutrons liberated in the source after $Be^9(\alpha, n)C^{12}$ reaction before coming out of it may be scattered elastically again in the beryllium nuclei within the source itself. The emerging neutrons then lose some energy which transfer to the recoil nuclei. The neutrons within the energy range 5.5 Mev to 8 Mev after elastic scattering attain the energy value near about 5 Mev. Whether a peak occurs or not can be checked in the following way. The energy of an elastically scattered neutron E_{el} for a given

energy of neutrons before scattering E_0 is again function of scattering angle $\bar{\phi}$ and is given by the relation

$$E_{el} = \frac{E_0}{(M+m)^2} \left[m \cos \bar{\phi} + (M^2 - m^2 \sin^2 \bar{\phi})^{1/2} \right]$$

where m = mass of the neutron and M = the mass of the nucleus under investigation (Be^9)

Again for a fixed neutron energy a uniform distribution in angle in centre-of-mass system corresponds to a uniform distribution in energy in the laboratory system. The maximum and minimum values of E_{el} corresponding to a fixed value of E_0 are calculated and plotted in figure 3 in the range from 6 Mev to 8 Mev. Now to determine the effect of varying neutron energies we need the excitation function of this. It is to be noted here regarding the result of this calculation that the assumption has been made that neutrons of fixed energy E_0 liberate neutrons with a uniform distribution of energy. Following the same type of calculation used by Whitmore and Baker (1950) the distributions of scattered neutrons may be obtained from the given range of energy of neutrons before scattering. If the number of neutrons having energies in the range dE_0 is proportional to dE_0 , and if each such particle after scattering gives $f(E_0)$ scattered neutrons and if these neutrons are spread uniformly over a range of energies ΔE_{el} then the number of such neutrons having energies between E_{el} and $(E_{el} + dE_{el})$ is proportional to $f(E_0) dE_0 \cdot dE_{el} / \Delta E_{el}$. The number of neutrons of this energy therefore may be calculated on this basis using the value of elastic scattering cross section at that energy to obtain $f(E_0)$. The elastic scattering cross section is taken equal to half of the total cross section σ_t at this energy. The σ_{el} was obtained from $\sigma_t^{(14)}$. The curve obtained is shown in figure 4. It shows the presence of a peak in the region of 4—5 Mev. There is however difficulty in interpreting the intensity of the peaks observed with the theoretical one.

The average energy of the continuous distribution of neutrons is 4.6 Mev. The effect of inelastic scattering in lead is mainly from the neutrons of this energy. But actually there is the contribution from neutrons of energies extending upto 11 Mev. This gives rise to a very complicated pattern. The effect of inelastic scattering of 4.6 Mev and also of 14 Mev neutrons has been studied in lead (Mandeville and Swann, 1951; Graves and Rosen, 1953; Whitmore, 1953). These results show an increase in number of neutrons in the low energy region and a peak near 1 Mev due to the excitation of the level near 3 Mev of naturally occurring lead. In our curve no sharp peak near 2 Mev was obtained using lead, and the increase of number of neutrons in the inelastic region is very small. Also the peak near 8 Mev is sharp using lead for which no proper explanation can be given.

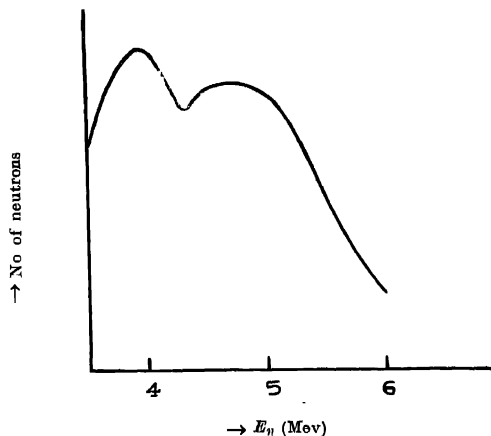


Fig. 4

No detail and precise analysis is possible because of the large statistical error and the complicated nature of the process because of the continuous energy distribution.

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